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A review of technical issues on the development of wind farms

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ABSTRACT

Energy is the prime mover of economic growth and is vital to sustain a modern economic and social development. Renewable energy applications have brought about significant changes in the Indian energy scenario. The identification and efficient use of various renewable energy resources are the thrust areas in energy development. Wind energy is one of the most environment friendly, clean and safe energy resources. The wind energy will continue to be the biggest renewable energy sector in any country in terms of both installed capacity and total potential. This paper reviews some important factors and techniques to be considered for wind turbine installations such as the wind energy resource assessment techniques, environmental factors, grid integration factors, control strategies, impact of offshore wind turbines and hybrid energy technologies, hydrogen production techniques, feed-in tariff mechanism, modeling of wind turbine components including generators, performance improvement techniques. The cost and economic feasibility of the wind energy conversion system as well as the control strategies of wind turbine generators have also been discussed.

Contents

1. Introduction

Wind power harvesting is today a mature technology which at windy locations is economically competitive with conventional power generation technologies [1]. India is a land with abundant wind resources. India's wind power has been experiencing rapid development since 1990. India is the second largest wind market in Asia with a total capacity of 15,880 MW. According to the International Energy Agency, in 2008, more than 400 million Indians did not have access to electricity [2]. The Installed Capacity (IC) of global wind energy at the end of 2011 was 237021.5 MW in 97 countries/ regions which is 20.29% more than that of 2010. All the wind turbines installed around the globe till the end of 2011 generate 500 Tera Watt hours (TWh) per annum which is 16.28%

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higher than that in 2010. The total installed capacity of grid interactive renewable power, which was 16817 MW as on 31.03.2010 was increased to 19,971 MW as on 31.03.2011 indicating a growth of 18.75% during the period. Out of the total installed generation capacity of renewable power, wind power accounted for about 71% as on 31-03-2011[3].

As on March 31, 2012, the installed capacity of the renewable energy based power generation was 24,503 MW which is about 12% of the total installed capacity of 199,626 MW [4]. The grid connected wind energy onshore potential and grid connected renewable energy potential in India are 100,000 MW and 662,881 MW respectively [5]. The potential wind power of India is estimated to be 49,132 MW. The wind power market penetration is expected to reach 8% of the total energy market penetration by 2018 [6]. The generation of electricity by wind turbines does not involve the release of carbon-dioxide. The government of India gives a subsidy to renewable electricity sources like wind and makes the wind power development more attractive to investors on wind energy. India was honored with the world wind energy award of 2005 for making an outstanding contribution of suitable wind power policies [7]. Public sector undertakings, public utilities and corporate bodies are being encouraged to invest in wind power projects to meet their electricity requirements. The Consolidated Energy Consultants Ltd., a leading consultancy organization, provides the micro details of explorations of windy locations, wind characteristics, wind farm layout and selection of most economical and best suited wind turbines.

The Indian Renewable Energy Development Agency was established as a public limited government company in 1987 for financing and promoting self- sustaining investment in power production from renewable energy sources. The Ministry for Non-Conventional Energy Sources started functioning as a separate ministry from 1992 with a view to develops all areas of renewable energy. To help develop an effective utilization of wind energy in India, the Centre for Wind Energy Technology was established in Chennai in the year 1998–1999. The wind resources are inherently intermittent and difficult to control in terms of power output. The stable wind turbine operation with the existing power grid can be accomplished by tackling the technical problems resulting from the unstable fluctuation of wind energy. Grid integration is the most interesting and exciting area of research in the world today. The wind energy resources are remote from the load and existing generation and therefore require the development of transmission. Activities related to wind farm design are continuing to grow on integration of wind energy into transmission and distribution grids. The advanced research capabilities on wind energy are expected to stimulate economic development, reduce energy costs, improve reliability and enhance environmental quality. This article gives a brief overview of various factors and techniques to be considered for wind energy development. The paper will be useful to the wind energy promoters to know the recent developments in the research carried out on wind energy fields and the researchers in the area.

2. Wind power resource assessment techniques

Several authors have worked on area such as wind resource assessments and its models, wind power potential and wind power density, site selection and site matching, estimating and forecasting of wind energy production and energy loss owing to wake effect. These reviews are based on wind-speed prediction and forecasting. The development of techniques for accurate wind-resource assessment under research and development is described as follows: Daniels (1988) presented wind data of four turbine siting methods and compared it with the wind speed estimates made prior to the project for large wind turbines located in Kahuku on the Hawaiian island of Oahu. The result produced the best trade estimates of both mean speed and ranking of the turbine sites [8]. Bechrakis et al. (2004) analyzed wind resources for an area using short term data correlated to a long term data set [9]. Redman (2004) assessed wind energy resources to the wind energy prospects of Saudi Arabia. The correct wind resource measurements taken for an area by using wind meteorological towers are essential in wind potential exploitation. Wind resources are known to be rarely consistent and vary with time, season, terrain type and height above ground. These factors are to be thoroughly investigated prior to any exploitation [10]. King and Hurley (2004) described the wind resource potential assessment of a wind farm by using Molded Site Data wind correlation method. The performance of this method of assessment resulted in expected accuracy [11]. Archer and Jacobson (2005) evaluated global wind power in the United States and the data analyses indicated that 15% of the data stations in the United States has the annual-average wind speed above 6.9 m/s (15.4 mph) at 80 m [12].

Singh et al. (2006) reviewed the wind-speed prediction, forecasting techniques and the methods for accurate assessment of wind-power potential. The assessment of power output from a wind turbine will be accurate, if the wind speed is measured at the hub height (30–50 m) of a wind turbine-generator. However, the existing wind data available at most of the meteorological stations worldwide are measured at a height of 10 or 20 m above the ground [13]. Rehman et al. (2007) carried out a study on wind resource assessment for Saudi Arabia [14]. Nguyen (2007) estimated the wind resources available in Vietnam [15]. Lackner and Manwell (2007) described an objective decision-making approach for wind resource assessment at site. A recursive dynamic program was used to evaluate the option for continuous measurement. The results indicated that it was an extremely effective method for reducing the average measurement time [16]. Sreevalsan et al. (2007) discussed the wind farm site assessment based on Measure-Correlate-Predict method by using Fast-Fourier Transforms and validated the result with measured data at the observed site [17]. Buflasa et al.(2008) carried out wind resource assessment for the development of the wind farms in the Kingdom of Bahrain [18]. Elamouri and Ben Amar (2008) have evaluated the wind speed characteristics and the wind power potential for the 17 locations in Tunisia at an altitude of 10 m above ground level [19]. Ziter and Lubitz (2010) investigated the use of vertical extrapolation method to reduce the uncertainty associated with tower-mounted anemometer wind speed measurements and performed an experimental study with a meteorological mast. The results indicated that the power law extrapolation could significantly reduce the uncertainty of wind speed predictions at hub-height level especially if concurrent wind speed measurements were available at multiple elevations. A porous disk wind tunnel test was also performed experimentally and compared with the three-dimensional wind speed measurements to identify the upper limit of anemometer placement. It was recommended that the topmost anemometer be positioned at one rotor diameter below hub-height [20].

Yoreley Cancino-Solorzano et al. (2010) evaluated the wind persistence properties using analytical methods to identify the best site for a wind farm in Mexico. The results indicated that the coastal areas have the best properties of wind speed persistence for the generation of electricity from wind energy [21]. Johnson (1978) determined Weibull parameters by using the Weibull distribution methods for the wind resource assessment to an economic design of wind electric systems [22]. Corotis et al. (1978) analyzed the seasonal characteristics of the wind speed persistence by using probabilities models and compared the obtained results with potential and exponential laws [23]. Wasynczuk (1981) described

the dynamic behavior of a class of wind turbine generators during random wind fluctuations. An adequate model of the wind is necessary to predict the dynamics of Wind Turbine Generator Systems (WTGS). The wind is a multidimensional stochastic process which depends on the time and spatial coordinates [24]. Duque et al. (2003) presented preliminary aerodynamic studies on rotor flows by using full Navier–Stokes codes and validated. They also studied the effects of transition and turbulence models of flows through wind turbines. The numerical solution has become increasingly useful since it helps to reduce time and cost in wind turbine development [25].

Lange et al. (2006) forecasted wind power using a numerical weather prediction model with statistical analyses of local measurements. The use of forecasting reduces uncertainty and makes planning more dependable, thus reducing the impacts of variability [26]. Yeh and Wang (2008) studied the generator capacity for wind turbines under various tower heights and rated wind speed using Weibull distribution. The wind speeds were parameterized by using cubic mean cube root and they were statistically modeled using Weibull probability [27]. Palma et al. (2008) showed how conventional techniques, linear models and cup anemometers could be combined with flow simulation by using computational fluid dynamics techniques (nonlinear models) and measurements by sonic anemometers in wind resource assessment, and discussed their relative merits in the characterization of the wind over a coastal region of cliff above the sea [28]. Buonanno et al. (2008) illustrated an overview on the physical backscattering mechanism that models on the wind signatures in Synthetic Aperture Radar images and described several strategies to derive wind map [29]. Mukinovic et al. (2010) presented a double multiple stream tube model as an engineering approach for design and optimization of Vertical Axis Wind Turbines (VAWT) and investigated the unsteady flow around a H-type rotor using computational fluid dynamics [30]. Omer (2008) used the power law method to determine the wind velocity at one level to another [31]. Ahmed Shata and Hanitsch (2008) presented electricity generation and wind potential assessment at Hurghada, Egypt [32]. Himri and Stambouli (2009) evaluated the wind energy potential in four selected sites in Algeria [33]. Getachew Bekele and Bjorn Palm (2009) investigated the wind energy potential at four different sites in Ethiopia and found variations in wind speed [34]. Xydis et al. (2009) studied the wind potential of Central Peloponnese in Greece for wind farm site selection. The implementation of available energy or exergy analysis methodology using wind speed forecasting model was used to provide a useful measure of actual utilization of energy from the existing available energy [35].

Bilgili and Sahin (2009) investigated the wind energy density in the southern and southwestern region of Turkey [36]. Fueyo et al. (2010) assessed the potential of on-shore wind energy in Spain by using a methodology based on a detailed characterization of the wind resource. The study indicated that the overall technical potential was approximately 1100 TWh/y; about 70 GW of installed wind power could operate with capacity factors in excess of 24%, resulting in an annual electricity generation of approximately 190 TWh, or 60% of the electricity consumption in 2008 [37]. Dahmouni et al. (2011) estimated the wind energy potential in the Borj-Cedria area of Tunisia and estimated the net energy output of seven 1.5 MW wind turbines by taking into account of the air density correction and the power losses in wind farm. This comparative simulation showed the difference in wind energy production and was used to choose the best wind turbine adapted to the site conditions [38]. Tande and Hansen (2004) analyzed opportunities for installing wind farms and identified numerous locations to install WTGs with favorable wind conditions to achieve high wind energy penetration worldwide [39]. Barnard (1991) evaluated three models designed for installation of suitable (siting) wind turbines in complex structure of different land areas [40].

Salameh and Safari (1992) determined the Wind Turbine Generator (WTG) speed parameters and the optimal WTG for a specific site based on capacity factor maximization. It also explained the factors affecting electricity production by a WTG including the mean wind speed of the site and more importantly, the characteristics of the windmill itself, especially the hub height, cut-in, rated, and furling wind speeds [41]. Billinton and Chen (1999) introduced the two risk-based indices designated as the Load Carrying Capacity Benefit Ratio and the Equivalent Capacity Ratio to determine the optimum site-matching of WTG for a specific wind site [42]. Janagmshetti and Rau (1999) conducted a case study on site matching of wind turbine generators and performed modeling of WTG capacity factor based on Weibull Probability Density Function [43]. Grady et al. (2005) used a genetic algorithm for placement of wind turbines by dividing the wind farm into square grids. [44]. Bell et al. (2005) distinguished between the explanations of social gap and the individual gap and suggested a different policy response to increase the wind energy capacity by developing a better understanding of wind farm siting [45].

Bazzi and Fares (2008) designed an interactive wind farm approach for Lebanon by using geographic information systems to ensure noise pollution reduction, cost estimation, accurate farm area and location, and also to show the number of turbines that fit in this area. The procedure was successfully implemented to locate the optimal site for a wind farm based on the user preferences and the characteristics of the site [46]. Yoreley Cancino Solorzano and Xiberta Bernat Jorge (2009) performed a statistical analysis of wind power in the region of Veracruz (Mexico.) and identified the coastal zone being the best site for electricity generation from wind [47]. Jowder (2009) analyzed the wind power and site matching of wind turbine generators in the Kingdom of Bahrain and the optimal WTG for a specific site defined by wind-speed probability distribution [48]. Li and Chen (2009) investigated site matching of the direct-drive wind turbine concepts based on the electromagnetic design optimization of Permanent Magnet Generator Systems (PMGS). The annual energy output was also presented using the Weibull Density Function. According to the design principle, the optimum permanent magnet generator was determined [49]. Serrano Gonzalez et al. (2010) described optimization of wind farm layout using an evaluative algorithm model and developed crossing and mutation specific operators to find out individuals within a family with different number of wind generators [50]. EL-Shimy (2010) performed an optimal site matching of WTG through improved formulation of the capacity factor at Gulf of EL-Zayt site in the Gulf of Suez region in Egypt and determined optimal output-power-curve for WTG [51]. Ma et al. (2011) presented a diffusion distance methodology for clustering wind turbines of large wind farm to simplify controller design, and operation and forecast of wind farm output and analyzed the spectral properties of the constructed Markov chain to identify the number of clusters [52]. Ahmed and Abul' Wafa (2011) presented a novel method of matching wind turbine generators to a site using turbine performance index in conjunction with a minimum deviation ratio between rated speed of *WTG* and optimal speed and resulting in minimum cost of energy (*COE*) to yield higher energy at higher capacity factor [53].

Finardi et al. (1998) evaluated different ideas on wind field modeling for wind energy applications in complex topography [54]. Kiehling and Cohn (2002) described the concept of using Supervisory Control and Data Acquisition (SCADA) in wind farms to predict short-term forecasts of the wind energy production before the energy can be sold. The SCADA system can automate the process of transmitting site performance data to the forecaster

to improve forecasting [55]. Kennedy (2005) pointed out that the benefits of large penetrations of wind power cannot be accurately estimated without considering the stochastic interaction among wind power variability, electricity demand, and the operation of other generators on the power system [56]. Grady et al. (2005) described the placement of wind turbines using genetic algorithms to maximize wind energy capture [57]. Voorspools and Dhaeseleer (2007) developed critical evaluation methods for wind-power appraisal [58]. Prasad et al. (2009) estimated the annual wind energy yield for the Vadravadra site in Gau Island in Fiji and also presented a method for finding the optimum wind turbine that can be installed at a site and the kind of wind turbine that should be installed at a site, where cyclone may hit the area. For harnessing wind energy from a wind farm, wind resource assessment needs to be carried out [59].

Xia and Song (2009) analyzed the wind energy scenario and its future perspectives in China. More than 90% of 750 kW wind turbines were domestically manufactured and China will be the center of the global wind energy market in future [60]. Kaigui Xie and Roy Billinton (2011) introduced an electrical energy production and reliability benefit index designated as the Equivalent Capacity Ratio (ECR) to indicate the electrical energy production and the annual utilization time. The ECR provided a useful index for a WTG to evaluate the energy production and the relative reliability performance in a power system, which is used to assist in the identification of the optimal WTG type for a specific wind site [61]. Neustadter (1985) presented a method for evaluating wind turbine wake effects on wind farm performance. A wake loss was an important factor in considering a wind park layout design [62]. Jenkins (1993) calculated the reduction of the wind speed in the wake stream of a turbine by assuming that the kinetic momentum of the air mass remained unchanged [63]. Milborrow (1998) reviewed wake and cluster studies of wind farm and predicted energy losses and increased blade loads. The technical issues in wind farms and supporting activities were also discussed [64]. Barthel et al. (2001) evaluated interface wake and boundary-layer models for utilization in developing offshore wind farms by using six models and conducted an experiment using SODAR to examine vertical wind speed profiles and wake dispersion for model development [65]. Lange et al. (2003) incorporated complex wake loss models of offshore wind farm for an optimization approach. Once the wake loss can be calculated based on wind turbine locations, the power curve function needs to be determined for estimation of the expected power production [66]. Nessler et al. (2009) investigated the effect of the periodic disturbances on turbine blade performance at low Reynolds numbers ($Re < 5 \times 10^4$). He used the highly loaded low pressure turbine blade with unsteady wakes to quantify the profile loss [67]. El-Osta and Califa (2003) carried out a feasibility study for a wind farm of 6.0 MW capacities in Libya and showed that the project was economically feasible [68]. Marafia and Ashour (2003) carried out an economical feasibility study and assessment of the potential of off-shore/on-shore wind energy as a renewable source of energy in Qatar and the result of which indicated the suitability of utilizing a small to medium-size WTG [69]. The main parameters describing wind resources are wind power generation and forecast accuracy. Therefore, the reviews based on wind resource assessment are important for the accurate and thorough monitoring of wind resource at potential sites in the process of selection and installation of wind turbines for wind power extraction.

3. Environmental impacts

Wind energy is considered as a promising and encouraging renewable energy alternative for power generation owing to its environmental benefits. Noise emissions are detrimental to wind turbine development. The environmental factors to be considered for wind turbine installations are reviewed below:

Joao Paula et al. (2011) estimated bird-strike mortality at wind farms by using dogs (annimal) as tools to improve bird-strike mortality estimates at wind farms and other anthropogenic structures that cause bird fatalities worldwide. Furthermore, they verified the efficiency of detection dogs searching for bird carcasses, and investigated the influence of several factors that affected the performance of dogs. The carcass decomposition rate, distances to the carcass and weather conditions significantly affect the efficiency of the working dogs [70]. Ryunosuke Kikuchi (2008) analyzed the adverse impact of the wind power generation on collision behavior of birds and anti-predator behavior of squirrels to reduce the collision risk at the hub. Wind farms kill millions of birds yearly around the world. Despite an extensive land use (2600–6000 m^2/MW), these impacts have been resolved by technological developments and proper site selection [71]. Lin Bo et al. (2011) designed and implemented an automatic measurement platform based on powerful LabVIEW for noise assessment of the Wind Turbine Generator Systems (WTGS) according to measurement method of IEC 61400-11 standard to ensure perfect functions, low costs and great practicality [72]. Bastasch (2006) analyzed the noise of wind power turbine during its operation and found that the noise radiation was still the major limitation in the tremendous development of wind energy [73]. Husky and Meadors (2001) performed an acoustic test on the Whisper H40 wind turbine to characterize its noise emissions in accordance with procedures described in IEC 61400-11 with minor modifications leading to the development of advanced wind turbines [74].

The Energy Research Centre of the Netherlands (2004) purchased Bruel & Kjær (B&K) products to indentify noise from WTGS according to IEC 61400-11. The noise measuring system based on B&K products needs much manpower and a long time [75]. Clifton-Smith (2010) presented a method of reducing the noise from wind turbines whilst retaining power production by using the numerical optimization technique. This noise reduction was attributed to an increase in angle of attack and Reynolds number. At a tip speed ratio of 5.5, a maximum of 1% decrease in power coefficient brings about a simultaneous decrease in total sound pressure level (2 dBA) [76]. Job (1988) reviewed various factors influencing the relationship between noise exposure and reaction [77]. Lethe et al. (2009) used 3D multi-body simulation tools to analyze and optimize the durability performance, noise emissions and overall yield of wind turbines to predict the loads that the different components need to transmit along the drive train from the blades to the generator [78].

Lee et al. (2010) demonstrated the design of 10 kW class wind turbines to reduce noise emission and analyzed the aerodynamic performance to reduce the wind turbine power loss and predicted the dominant broadband noise sources with the help of semi-empirical formulas. The new optimized wind turbine airfoil showed 2.9 dB reductions in total sound pressure level and achieved a higher aerodynamic performance [79]. Wagener and Doberty (2007) explained lightning strikes and surge protection to prevent the WTG from being struck by lightning, minimizing downtime and maintenance costs. Franklin-type lightning rods were installed in the wind turbines to protect them against lightning strikes [80]. Wang and Zhang (2009) proposed an efficient method to predict the lightning electromagnetic interference to electronic devices installed inside wind turbine towers and provided guidelines for a lightning protection design of the electronic systems according to the calculated results. The computed results were compared with those obtained by an appropriate finite difference method, which confirmed the validity of the proposed method [81].

Cotton (1999) discussed the performance of wind farm earthing systems under both power system frequency and lightning current energization. He also described the various design factors of wind farm earthing system [82]. Lorentzou and Hatziargyriou (2001) investigated an effective design of extended grounding systems as in the case of wind farms grounding in order to prevent electrical installation from excessive over voltages and potential gradients when lightning occured or in case of short circuit [83]. Shindo and Suda (2009) carried out the lightning risk assessment of the WTGs and it was compared with field experiences [84]. Olatz Ukar and Inmaculada Zamora (2011) analyzed the wind farm grounding system geometries in the context of lightning strikes. The damage due to a lightning strike can be reduced if the high current is quickly conducted to the ground [85]. Grcev (1996) developed computational models for transients in large grounding systems of wind farms [86]. Chen et al. (2011) illustrated a case study of greenhouse gas emission in Guangxi. The non-renewable energy saving in China was estimated at 1.22×10^{10} MJ and the reduction in greenhouse gas emissions was calculated to be 1.03×10^{9} kg CO_2-eq by a typical wind farm during its 20 years of operating period. The concrete results have supported effective wind power policy making implications in China [87].

Hart and Jacobson (2011) described a new generator portfolio planning model to quantify the carbon emissions associated with systems that included very high penetrations of variable renewable energy using Monte Carlo simulation [88]. Joselin Herbert et al. (2005) reviewed the wind energy technologies and discussed the global climate change to reduce carbon dioxide emissions [89]. Crawford (2009) presented life cycle energy and greenhouse emissions analysis of the wind turbines based on a hybrid embodied energy model [90]. Chen and Zhang (2010) reviewed the direct greenhouse gas emissions in China of 7.46×10^{12} kg CO_2-eq [91]. Lindley (1994) analyzed the prospects and problems of 22 wind farms with a total installed capacity of approximately 140 MW in U.K. This study projected that these wind farms could generate about 360 GWh in a full year and provided the electricity needs of about 250,000 individuals and avoided the emission of about 400,000 tones of CO_2 each year [92]. Pablo del Rio Gonzalez et al. (2005) explored the Kyoto Protocol project mechanisms for the deployment of renewable energy sources in Europe to increase the percentage of electricity from renewable energy sources and to control the Green House Gas (GHG) emissions [93].

Saber et al. (2011) presented a smart grid model by maximum utilization of gridable vehicles and Renewable Energy Sources (RESs). The smart grid model offers the best potential for maximum utilization of RESs to reduce emission from the electricity industry [94]. Martin et al. (2008) performed a comprehensive environmental system analysis of the possible CO_2 reduction of an offshore wind farm in Germany [95]. Lenzen and Munksgaard (2002) carried out a worldwide survey on environmental performances of wind farms. The result showed that most of the modern wind turbines differed from small capacity WTGs but there was a relatively large variation in energy and CO_2 intensities [96]. Meyerhoff et al. (2010) analyzed landscape the externalities from on-shore wind power in Germany and observed that many residents disapproved of the wind energy because of its associated negative impacts like visual impacts [97].

Pablo Del Rio (2006) analyzed the renewable energy Clean Development Mechanism projects and studied the impacts of those options on different variables to encourage GHG mitigation and to enhance sustainable development opportunities [98]. Rogers and magee (2007) performed a strategic environmental assessment to identify suitable locations to install wind farms. It can be sited in the least ecologically sensitive locations possible [99]. Roy and Traiteur (2010) analyzed the impact of wind farms because of surface temperature and identified the impacts of wind farms on local weather conditions in many regions of the world. The impacts of wind farms on the local weather can be minimized by changing the rotor design or by installing wind farms in regions with high natural turbulence [100]. Bosley and Bosley (1998) conducted a qualitative and quantitative research to determine perceptions and attitudes regarding the wind energy development in California. The results indicated that realization of large wind farm projects was being affected by the local opposition which existed partly because of lack of knowledge about the technical maturity and economics of today's wind power and visual intrusion. The wind industry needs to continue improving its performance as well as its communications with all affected parties [101]. Jackson (2007) explored the effects of wind farms on radar system components and their impact on the overall performance of a radar system. The construction of wind farms will have a negative effect on both air traffic control and air defenses radar and many wind farm developments fail owing to objections from radar stakeholders [102].

Danese et al. (2008) highlighted the advantages of several techniques of 3D geo-visualization and improvements obtainable by means of geographical analysis as a support for environmental impact assessments in a region located in southern Italian Apennine with elevated wind power. The noise produced from the wind turbine created strong opposition and public resistance to wind turbine generator placements [103]

Delucchiand and Jacobson (2010) evaluated the feasibility of providing all favor of energy for all purposes in the world, from wind, water and the sun and concluded that barriers to a 100% conversion to wind, water and the sun power worldwide were primarily social and political, not technological or even economic [104]. Peter Fristrup (2003) presented and discussed some of the obstacles related to using tradable green certificate system as a part of the energy policy in Denmark. The most prominent obstacles related to managing the coexistence of multiple types of renewable energy suppliers with one policy instrument were also discussed [105]. Daugbjerg and Svendsen (2011) compared the wind turbine industry policy and organic farming sector policy It was demonstrated that government intervention in the wind turbine industry had emphasized the use of policy instruments designed to increase demand for wind energy, whereas organic farming policy has put more emphasis on instruments motivating farmers to increase supply [106]. The environmental impacts of the wind farms can be minimized by changing the rotor design and installing the wind farm at suitable locations.

4. Grid integrations techniques

Wind farms have a significant influence on the operation of power systems. Several technical and operational issues with increased wind power penetration are strongly essential for emerging wind power systems. The grid connected wind turbines may cause problems in power quality, such as voltage variation and flicker, and therefore, the connection of wind farms requires new connecting rules to avoid negative effects on the existing electrical systems. The grid related problems of wind farms are reviewed as follows.

Sun et al. (2010) provided an overview to the latest research issues related to the integration of wind farms with Variable Speed Wind Plant Systems (VSWPSs). The structure and control of VSWPSs are much more different from traditional Fixed-Speed Wind Plant Systems (FSWPSs), which make VSWPSs more powerful than FSWPSs and flexible to connect with power grids. While VSWPSs improve the stability of systems to some extent, several new problems are introduced into the power grid, such as the advanced controller significantly increasing the complexity of the

system and the power converter emitting harmonic currents thereby reducing the power quality [107]. Hansen et al. (2009) presented an overall perspective on contemporary issues like wind power plants and grid integration to discuss the impact of emerging new grid connection requirements on modern wind turbines and suggested the need for researches on wind turbines based on an integrated design and control approach [108]. Albu et al. (2010) discussed the effective integration of dispersed generation into intelligent networks with low-power to avoid losses in energy transfer by using a Direct Current (DC) layer within the distribution networks, at least where the energy is produced in DC form. Specific indicators were formulated to characterize power quality issues of DC systems [109].

Burke and Omalley et al. (2011) studied the factors influencing the wind energy curtailment. Wind generation connections are necessary for significant wind integration into congested transmission networks. The results indicated that errors of curtailment estimation could be reduced by appropriate wind data year-length, sampling-rate choice and through a pragmatic approach to system parameter uncertainty [110]. Molinas et al. (2007) presented an overview of the STATCOM as a solution for the voltage quality problems related to the interconnection of fluctuating renewable energy sources to the power network. Experimental results verified the validity of the simulation results indicating that the STATCOM was better than the grid interface of renewable energy sources with induction [111]. Joshi and Mohan (2006) had tried to solve the problems related to grid connection of wind turbines by using series compensation. A new scheme was proposed for the Doubly Fed Induction Generators (DFIG) connected to grid. This scheme helps in limiting fault currents as well as in balancing the voltages seen by DFIG [112]. Naik and Jangamshetti et al. (2011) presented a critical study of modulation strategies for three levels Diode Clamped Voltage Source Inverter (DCVSI) for the grid connected wind turbine. It was observed that the three level DCVSI suffers from a narrow pulse width and a capacitor voltage imbalance, which would be predominant with higher rated wind turbine. The study also revealed that the existing modulation techniques, even though popular in drive application, failed to meet the present requirements of grid connection [113].

Van Dessel et al. (2010) discussed the simulation of a power electronic converter used for the grid connection of a permanent magnet generator designed for variable speed wind turbines [114]. Basu et al. (2008) presented Particle Swarm Optimization technique to determine the optimal size and location of the Distributed Energy Resources (DERs) of the micro grids in a meshed network for maximizing the economic benefits by minimizing the line loss [115]. Gagliano et al. (2005) presented a probabilistic approach for an optimal unit sizing of a grid connected Hybrid Solar Wind Power System (HSWPS) without storage. The Optimization technique used is based on the sequential quadratic programming method. A case study was carried out on an on-site system with the option of reverse power flow into the grid, using the data on solar insolation and wind speed obtained through real measurement [116].

Tapia et al. (2009) presented a systematic methodology for the smooth connection of wind-turbine-driven Doubly Fed Induction Generators (DFIGs) to the grid, and thoroughly examined synchronization of the voltage induced in the DFIG open stator to that of the grid, which needed to be accomplished prior to connection [117]. Linh (2009) simulated the wind speed model, wind turbine model, and flicker meter model using Matlab/Simulink software to investigate the impact of power quality on load and operation of wind power system. The voltage fluctuation and flicker and harmonics are the main aspects of power quality problems of the grid connected wind farms. The fluctuation of wind farm output and grid voltage due to the random fluctuation of wind speed and how inherent characteristics of wind turbines might cause flicker severity were also investigated [118].

Dragomir et al. (2009) presented the technical requirements related to the connection of the wind power plants to the main grid to facilitate the orientation of adequate type of wind turbines to wind farm site [119]. Fajardo et al. (2009) using a detailed modeling, assessed the transient stability of grid-connected wind turbines, combining grid-connection, wind turbine flexibility, and induction generator stability features to identify the critical clearing time and critical speed [120].

Senturk et al. (2009) modeled, controlled, and simulated three-Level (3L) Neutral Point Clamped (NPC), Flying Capacitor (FC), and H-bridge (HB) Voltage Source Converters (VSCs) as a grid-side full-scale medium voltage (MV) converter for the grid connection of a hypothetical 6 MW wind turbine. The grid connection circuit (without capacitive switching ripple filters), the 3L –HB-VSC was expected to be superior to the 3L –NPC- and -FC-VSCs with respect to power density and reliability [121]. Rockhill et al. (2011) described the design procedure and performance of grid filter for a medium-voltage NPC converter to be adopted for a multi-megawatt wind turbine. They also demonstrated a frequency-domain-model-based approach to determine the optimum filter parameters that provide the necessary performance under all operating conditions given the necessary design constraints. A new passive-damping technique was also proposed to provide the necessary damping with low losses [122]. Li et al. (2009) proposed and analyzed a new 9-level active NPC converter to achieve filterless grid-connection with benefits in terms of cost, efficiency, power density and reliability of the wind turbine system [123].

Blasco-Gimenez et al. (2009) introduced a method to control the HVDC link voltage and current by modifying the off-shore AC grid voltage, which, in turn, was controlled by the wind turbines. Simulation results showed good performance in a steady state and during on-shore AC grid faults [124]. Liserre et al. (2011) reviewed the most-adopted wind-turbine systems, the adopted generators, the topologies of the converters and grid connection issues as well as their arrangement in wind farms [125]. Song et al. (2008) presented a set of simulations of the structural dynamic response of a typical fixed speed wind turbine equipped with an induction generator. The grid faults were also analyzed by using simulation packages, namely fatigue, aerodynamics, structures and turbulence to model the electrical and mechanical aspects of a wind turbine [126].

Landsverk et al. (2009) designed circuit breaker panels with dimensions suitable for wind farm applications to secure a good fit of circuit breaker panels for distribution networks [127]. Gomes et al. (2009) explained the minimum connection requirements and grid codes for the clean energy projects, including wind farms, small hydroelectric plants, biomass, micro-turbines, photovoltaic fuel cells and other kinds of generation [128]. Tsili and Papathanassiou (2009) provided an overview of the grid code technical requirements regarding the connection of large wind farms to the electric power systems and demonstrated the recent developments in wind turbine technology [129].

Arifujjaman et al. (2009) performed a reliability analysis of the grid Power Conditioning System (PCS) for both the Permanent Magnet Generator (PMG) and the Wound Rotor Induction Generator (WRIG)-based small wind turbine generation systems. This research indicated that the WRIG-based small wind turbine with a simple PCS was a much better option than PMG with PCS for small wind energy conversion system [130]. The technical requirements and latest research issues related to the connection of the wind farms to the main grid are to be considered in order to avoid or reduce the loss of power. The grid integration issue has caused several new challenges to the wind turbine design and development. One solution for increasing the use of renewable

energy is to find new strategies to promote the connection of distributed energy resources within the existing power system. The grid interfacing systems for any wind farms need careful planning to assess its steady state impact on grid regarding voltage, power factor, and active/reactive power losses. Factors influencing voltage stability of the local grid interconnected with the wind farm were also reviewed.

5. Control strategies of WTGs

Wind stochastic results in fluctuations in power as well as undesirable dynamic loading of the drive train during high turbulence. The wind turbines experience both fatigue and extreme loads. A well-designed control system for WTGs enables more efficient energy generation, better power quality and the mitigation of aerodynamic and mechanical loads resulting in increased life of the installation. The objectives of wind turbine control are to maximize energy capture and alleviation of drive train fatigue loads. It requires an efficient control strategy to minimize the rotor instantaneous power oscillations, and consequently limits the dc-link voltage fluctuations. The reactive power control, pitch control, adaptive control, active control and other controls to regulate wind power production from WTGS have been reviewed as follows: Hinrinchsen and Nolan (1982) studied the dynamics and stability of wind turbine generators Although both speed and power can be selected as the controlled variable in a WTGS, the speed control is considered dynamically better than the power control [131]. Im and Song (2009) proposed a simple and helpful reactive power control analysis model of voltage variation in order to predict the voltage variation at PCC (Point of Common Coupling), when a wind turbine is connected in an isolated grid using PSCAD/EMTDC Simulation and the field measurement data of the voltage variation during the wind power generation. This voltage variation is proportional to the product of the line impedance from the ideal generator to the PCC and the wind turbine output current [132]. Ahmet Serdar Yilmaz and Zafer Ozer (2009) proposed an artificial neural network-based pitch angle controller for power regulation above the rated wind speed by multi-layer perceptrons with back propagation learning algorithm and radial basis function network to improve the quality of power generated from wind turbines [133].

Yongwei et al. (2009) introduced the operating principle and design of control system for an electric pitch system of wind turbine. The simulation and experiment studies were performed using MATLAB and indicated that the new system generate superior results over conventional system [134]. Slootweg et al. (2003) represented a general model for representing variable speed wind turbines in power system dynamics simulations and reported pitch control for power output and speed fluctuations from wind turbine generator. The transient performance could be enhanced by blade pitch control on the turbine side [135]. Geng and Yang (2009) explained robust pitch controller for output power leveling of variable-speed variable-pitch wind turbine generator systems. The classical methods are traditionally utilized in WTGS control; these solutions are not completely adequate since the resulting controllers do not provide sufficient damping to system [136]. Liebst (1983) studied the design of a pitch control system for large scale wind turbine using the classical linear quadratic Gaussian optimal regulator approach to alleviate the problems associated with shear, tower shadow, and gravity phenomena, such as shortened lifetime and noise generation. This pitch control system reduced the vibration and noise of WTGs and increased annual energy output [137]. Busca et al. (2010) implemented the most dominant control strategies on a Permanent Magnet Synchronous Generator (PMSG) of 2 MW wind turbine using Direct Torque Control (DTC) and Field Oriented Control (FOC) methods and compared the performance of the two control strategies. The pitch controller was used to limit the output power produced by the turbine with different test [138].

Jelavic and Peric (2009) presented a novel approach to the wind turbine control intended for a wind turbine operation during strong and gusty winds by combined use of generator electromagnetic torque and pitch control. They described the classic wind turbine control system and outlined the process of the control system design. Then the proposed control approach was validated against the performance of a fine tuned classic control system Testing of the control system was performed according to international standards using a professional wind turbine simulator [139]. Pujante-Lopez et al. (2009) described the modeling of wind turbines with Double Fed Induction Generator (DFIG) and implemented a pitch angle control to limit the generator speed during grid disturbances and in normal operation under high wind speeds. They also described the variation of power capture with pitch angle control for 2 MW wind turbine [140]. Wang et al. (2010) introduced the operating principle of the electrical pitch system of megawatt rated wind turbine-driven generator with the permanent magnet synchronous motor to provide an effective way to test the performance and reliability of the electrical pitch system in the ground. Electrical pitch system has been widely applied in the adjustable pitch wind turbine because of its simple structure, facility to impose a variety of control strategy, and high reliability [141].

Freeman and Balas (1998) applied the adaptive control methods to wind turbine control problems. The wind turbines operate in highly turbulent and unpredictable conditions. These complex aspects of wind turbines make them attractive candidates for the application of adaptive control methods [142]. Frost et al. (2009) developed an adaptive theory and extended a direct adaptive control approach to handle the adaptive rejection of persistent disturbances for utility-scale wind turbine for speed regulation [143]. Hafidz and Basu (2008) used a passive control to mitigate the voltage sag or swell and power interruption with zigzag transformer [144]. Gautam et al. (2011) designed a supplementary control for the DFIG power converters and also proposed the idea of adjusting pitch compensation and maximum active power order to the converter in order to improve the inertial response during the transient with response to drop in grid frequency. The damping power system oscillations were observed and validated by Eigen-value analysis [145]. Rotea et al. (2010) investigated an active structural control of offshore wind turbines. The results were compared to the optimal passive control system, and the additional achievable load reduction using active control was quantified [146].

Ronilson Rocha (2011) presented a sensor-less control for a variable speed wind turbine operating at partial load in order to eliminate the direct measurement of the wind speed. The estimated aerodynamic torque was used to determine the optimal reference of the speed control for maximum energy conversion [147]. Whei-Min Lin et al. (2011) designed a recurrent fuzzy neural network (RFNN) controller for wind generation system with a high-performance model reference adaptive system (MRAS) observer for the sensor less control of an induction generator (IG). The modified particle swarm optimization (MPSO) was adopted to adapt the learning rates in the back-propagation process of the RFNN to improve the learning capability. The proposed output maximization control was achieved without mechanical sensors such as the wind speed or position sensor, and the control system will deliver maximum electric power with light weight, high efficiency, and high reliability [148]. Simoes et al. (1997) developed fuzzy logic-based intelligent control of a variable speed cage machine wind generation system. The fuzzy neural network (FNN)

possesses advantages and it combines the capability of fuzzy reasoning and the capability of artificial neural network [149].

Rahim and Nowicki (2011) presented a grid-connected wind generation system with a robust susceptance controller to cater the reactive power requirement and evaluated the robustness of the controller through optimally tuned PID controllers. The simulation results show that the robust controller could effectively restore normal operation following emergencies like sudden load changes, wind gusts and low voltage conditions. Wind turbine driven induction generators are vulnerable to transient disturbances like wind gusts and low voltages on the system [150]. Bossanyi (2000) designed closed loop controllers for wind turbines to maintain power output at rated power and reduce aerodynamic loads on the turbine. A turbine operating at or above the rated wind speed needs a method to maintain the rated generator speed, otherwise the generator and power electronics system could overheat and the aerodynamic forces on the machine could leading to component fatigue or system failure [151]. Tan and Islam (2004) proposed optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors and determined the optimal rotor speed using the estimated value, and also proposed a new technique to capture the maximum energy without using the wind speed sensor [152].

Rathi and Mohan (2005) discussed a novel control strategy for Low Voltage Ride Through (LVRT) for wind turbines with DFIG [153]. Molinas et al. (2008) discussed the low voltage ride through LVRT of wind farms with cage generators using STATCOM compared to thyristor controlled static variable compensator (SVC) and proposed an analytical approach based on torque-slip characteristic to quantify the effect of the STATCOM and the SVC on the transient stability margin [154]. Yu Liu et al. (2008) used an additional circuitry which is a five-level cascade multilevel inverter based STATCOM to improve the fault ride through the control strategy of wind farm as well as to mitigate voltage fluctuation [155]. Ni et al. (2009) described a 4-phase interleaved boost converter for maximum power extraction from a small wind turbine and adopted a field programmable gate array based digital converter control system with discontinuous conduction mode control strategy. The modeling of the wind turbine system as well as power converter was studied by simulating analysis in MATLAB/SIMULINK [156]. Hori et al. (1999) described slow resonance ratio control for vibration suppression and disturbance rejection in WTG system. The driven train can be modeled as a set of masses coupled through flexible connections [157].

Grabic et al. (2010) analyzed the control problem of the fixed speed WTG system based on the grid connected PMSG drive train and series converter located in its star point and provided a basis for the development of the control algorithm to an active damping of the system. The performance of the system and control algorithm was validated by means of simulations and tests performed on the experimental setup [158]. Lazaro et al. (2010) studied the dynamic coupling and investigated a composite load control for wind turbines. The results showed significant mitigation of damage equivalent loads in the tower fore-aft, and low speed shaft tilt and yaw bending fatigue when compared to baseline. The composite controller achieves significant load reduction without the need for filtering out the effects of other channels, as would be required in the Multiple Single-Input Single-Output (MSISO) design [159]. Darrow et al. (2009) determined the crucial loads on wind turbines by analyzing multiple design-load-cases using advanced controllers [160]. In order to cope with the non-linearity in the WTGS and the continuous variation in the operating point, a controller is suggested to provide near optimal performance within the whole operating region. The control systems play a very vital role in wind power generations.

6. Off- shore wind turbine technologies

The need, objectives, models, benefits, and impact of the offshore wind turbines to understand the real behavior in the marine environment are briefed below: Arora et al. (2010) explained the total installed off-shore wind capacity amounted to 3522.4 MW in 2011 from 13 countries, out of which 396.8 MW were added during year 2011. The U.K. established a strong growth for the off-shore wind turbine with a total offshore capacity of 1524.6 MW. Europe is still the number one continent accounting for almost 93% of the total off-shore installation. China, Japan and 12 European countries are involved in off-shore wind energy generation [2]. Ki-Hak Lee et al. (2010) presented the selection procedure of a potential site for an off-shore wind farm around Jeju Island using the optimization technique based on artificial neural network models and genetic algorithm model to evaluate the wind resources of the proposed site [161]. Foti et al. (2010) had done a feasibility study of an off-shore wind farm and developed an original automatic optimization procedure in order to determine the dimensions of the design foundation, which satisfied the prescribed static verifications and provided the lowest costs. The scour process at the basis of the foundation and the wave run-up on the structure had also been taken into account. Finally, the problems related to the laying and the maintenance of electrical connection cables were also discussed [162]. Roddier et al. (2010) summarized the feasibility study conducted for the Wind Float technology and focused on the design for wind turbine floating foundations. It had drawn synergies from the oil and gas off-shore platform technology. The structural analysis between the hydrodynamic loading and the structural response was performed using an aero servo-elastic software package [163].

Bhattacharya and Adhikari (2011) experimentally and analytically investigated the dynamics of an off-shore wind turbine tower model to obtain the natural frequencies and the damping factors. The experimental results showed that the natural frequencies and the damping factors of the wind turbine tower change significantly with the type of soil/foundation and that the frequency of vibration was strongly related to the stiffness of the foundation [164]. Ren and Ou (2009) studied and simulated the dynamic process of the collision between a typical 3 MW Offshore Wind Turbine (OWT) model with monopile foundation and a simplified 2000 t-class ship model using LS-DYNA explicit code. They proposed a crashworthy device for OWT to guide the ship to run away from the main OWT structure and reduce the damage of the ship and OWT to some degree during side impact [165]. Lykke Andersen et al. (2011) initiated a physical model test study to clarify the wave run-up on cylindrical piles for different values of diameter to water depth ratios (D/h) and different wave heights to water depth ratios (H/h) for both regular and irregular waves. The wave run-up on foundations is a very important factor in the design of entrance platforms for offshore wind turbines [166].

Schroder et al. (2010) discussed the impact of the off-shore grid in Swedish, German and Danish zones, and explained several design options with regard to cabling in European power markets [167]. Bresesti et al. (2007) studied HVDC connection of offshore wind farms to the transmission system and identified that DC systems isolate wind farms from faults on main power system. The presence of MV and HV cables can cause undesirable overvoltages [168]. Morton A.B. et al. (2006) analyzed economics of grid connection design for off-shore wind farms by considering AC transmission system and investigated the site-specific distance from the coast exploiting HV-DC for large wind farms, over 1000 MW [169]. So (2007) presented the offshore wind turbine installations based on optimal reliability [170].

Sorensen and Tarp Johansen (2005) described reliability based optimization and optimal reliability level of offshore wind turbines [171]. Hameed et al. (2011) identified the need, objectives, method,

benefits, and application of a proposed reliability and maintainability database of off-shore wind turbines. The potential challenges and issues pertaining to these data-bases were also categorized to understand the real behavior of off-shore wind turbines [172]. Rados et al. (2001) compared six wake models and presented new single wake results against experimental data at Vindeby and Bockstigen wind farms to improve the overall performance of off-shore wind farms [173]. Frandsen et al. (2006) using analytical modeling, calculated the wind speed deficit in the downstream of the large offshore wind farms created the wake [174]. Due to social and political reasons the trend has been shifted largely from on-shore to off-shore wind farms. The off-shore wind energy production faces a wide range of new challenges in design, development, manufacturing, installation, and maintenance and operation. These reviews are essential to understand the development of off-shore wind farms.

7. Hybrid energy techniques

Several studies on hybrid energy systems have been reviewed as follows: Bitterlin (2006) modeled a reliable combination of wind and Photo Voltaic (PV) power generation and an energy storage system for remote radio base station sites without utility power [175]. Bansal et al. (2011) presented an Artificial Intelligent method to design the hybrid PV/wind system by using Meta Particle Swarm Optimization Technique for the effective use of hybrid energy system and to avoid the possibility of local minimum trap [176]. Moriana et al. (2010) studied the feasibility of a hybrid wind-PV power system to meet the load requirements of remote village electrification and developed a strategy to optimize the size of the energy generation and storage subsystems. The results showed that the more reliable solution was that in which 80% of the load was covered by PV and the other 20% by the wind turbines [177].

Shaahid et al. (2010) analyzed the wind speed and solar radiation data of Rafha, KSA, and assessed the technical and economic potential of hybrid wind- PV-diesel power systems to meet the load requirements of a typical remote village Rawdhat Bin Habbas with an annual electrical energy demand of 15,943 MWh. The study showed that for a given hybrid configuration, the number of operational hours of diesel generators decreases with increase in wind farm and PV capacity [178]. Deshmukh (1982) presented the probabilistic models for reliability analysis of combined Wind-Electric and Conventional Generation Systems (WECGS) [179]. Gavanindou et al. (1992) described a probabilistic method for predicting the performance of wind–diesel energy systems [180]. Bowen et al. (2003) collected and analyzed 15 months duration field data from a small remote wind–diesel power system at a coastal farm site and focused the performance of the 10 kW Bergey wind turbine [181].

Bowen et al. (2001) calculated the performance of a remote wind-diesel power system with the capacity factor (average power output/rated power) of 14% [182]. Benitez et al. (2008) investigated the integration of wind and hydropower using a nonlinear mathematical optimization program in Alberta, Canada, and found that the combination of wind and hydropower could virtually eliminate the back-up generation from gas-fired plants [183]. Katzenstein et al. (2010) estimated an annual production from 16 modeled 1.5 MW capacity turbines located throughout the Central and Southern Great Plains of the United States (US), for 1973–2008, and compared this with the observed hydro power in the US over the same period. It is interesting to note that the longer term (monthly or annual) variability in output potential of interconnected wind sites can be much less than the long-term variability of output potential of hydropower [184].

Monjean et al. (2010) presented the impact of hybrid wind generators and energy storage systems in a competitive market and technically constrained electrical systems. Simulation results showed that the correct location and sizing of the storage system increased wind production recovery [185]. Honnery and Moriarty (2009) estimated global hydrogen production from wind and analyzed the economic feasibility of a wind-hydrogen energy system with a wind turbine [186]. Milligan and Factor (2000) explained that interconnecting the geographical distribution of wind, solar, and wave farms to a common transmission grid smoothes out the electricity power supply significantly [187].

Stoutenburg et al. (2010) estimated the power output variations of co-located offshore wind turbines and wave energy converters in California. The combined energy from co-located wind and wave farms reduces variation of wind and wave power individually [188].Chung and Ju (2010) explained a hybrid design of vertical axis wind turbine (VAWT). The modified Darrieus-type windmill by adapting the VAWT system improved the wind power efficiency [189]. The hybrid energy systems such as hybrid PV/wind system, wind-PV-diesel system, wind-diesel power system, wind-storage system, wind- hydropower and wind turbines and wave energy converters are useful for further research in hybrid energy systems to meet the power requirements of any country.

8. Hydrogen production

The use of wind energy to generate electricity is well accepted and installing additional new wind energy capacity was being installed each year. Hydrogen is the energy carrier of the future power because it can be used to store intermittent non-conventional source of energy. The economical feasibility, design, simulation and performance analyses of hydrogen production from renewable energy have been reviewed as follows: Santarelli et al. (2004) reported the design and analysis of stand-alone hydrogen energy production system with three different renewable sources such as solar energy, hydraulic energy and wind energy in order to supply the electricity needs of a residential user in a mountain environment in Italy. It has been found that in that mountain environment, it is absolutely inconvenient to use the wind source. The seasonal storage of the RES in form of hydrogen is the lowest with the solar irradiance and it requires a higher hydrogen seasonal storage because of the availability of the micro-hydro source is less constant than those of solar irradiance [190]. Afgan et al. (2007) have reviewed the potential of multi-criteria assessment of hydrogen production from renewable energies. The renewable options evaluated with a multi-criteria method include the indicators such as performance indicator, the market indicator, the environment indicator and the social indicator. The multi-criteria procedure for evaluation of hydrogen energy systems proves that the sustainability index rating is an effective tool for decision making [191]. Contreras et al. (2007) analyzed the simulation of the power control system of a 250 kW plant for the generation of hydrogen via electrolysis, using photovoltaic solar energy. The results received conformed to high energy yield [192].

Elam et al. (2003) studied the technical and economical feasibility to collaborate and address the important barriers of hydrogen production from renewable energy for meeting the world's energy requirements. The collaborations have made advances in renewable hydrogen production and development of tools to access and optimize the production systems of integrated hydrogen energy [193]. Sherif et al. (2005) reviewed the technology and economical feasibility of hydrogen production from wind energy. The uses of hydrogen enhance the possibilities of wind power competitiveness. The review indicated that

wind - hydrogen integrated systems will draw more attention in the near future [194]. Bokris and Veziroglu (2007) estimated the price of hydrogen production from wind and solar energy sources. The cost of hydrogen production from wind and solar photovoltaic is less than $3 and $5 an amount equivalent in energy to thatof a gallon of gasoline respectively. The renewable sources yield energy at around one-half the cost of nuclear fission [195].

Greiner et al. (2008) conducted a case study on the production of hydrogen from wind energy in Norwegian island to calculate hydrogen cost. The hydrogen cost amounted to 2.8 € /kg and 6.2 € /kg for the grid-connected and isolated system, respectively. The grid-connected system is more economical than isolated system [196]. Segura et al. (2007) analyze the minimum requirements on energy efficiency of wind-powered hydrogen storage system. The simulation of a wind park shows a direct dependence of the economical profit on the energy efficiency of this hydrogen backup system [197]. Dutton et al. (2006) described the wind-powered hydrogen production systems to identify possible drawbacks and assessed the sizing and economics of a wind-hydrogen production plant. It resulted in the construction of a demonstration wind-powered hydrogen production plant in Italy [198]. De Battista et al. (2006) proposed a novel power control for a wind hydrogen energy system using the concept of the reference conditioning techniques and slide mode control theory to maximize efficiency in wind energy system. The loop guarantied the safe operation of the electrolyzer and improving the conditions for hydrogen production [199]. Gandia et al. (2007) conducted a performance analysis of an alkaline water electrolyzer under emulated wind conditions for renewable hydrogen production. It explained the special care to be considered when connecting electrolyzer to wind energy conversion system. [200].

Korpas and Greiner (2008) explained the overview of the opportunities for combining wind power and hydrogen production in weak grids and also presented a logistic simulation model for performance assessment of wind- hydrogen plants. It is indicated that the penetration of wind power can be increased by using electrolytic hydrogen production as a controllable load. The results indicated that there are large benefits of using the grid as backup for hydrogen production in the periods of low wind speed [201]. Fco Javier Pino et al. (2011) analyzed the hydrogen production in a wind-hydrogen system operating in “wind-balance” mode and also analyzed the influence of wind turbine power curve and electrolyzer operating temperature on hydrogen production in wind-hydrogen systems, using a mathematical wind turbine model and a dynamic electrolyzer model. The annual hydrogen production in a wind-hydrogen system is overestimated by 33.6%, when they are compared with mathematical models. The hydrogen production is overestimated by 3%, when compared with a dynamic electrolyzer model [202]. Archer and Jacobson (2007) evaluated the benefits of interconnecting wind farms for 19 sites, located in the mid-western United States. It was found that an average of 33% and a maximum of 47% of yearly averaged wind power from interconnected farms can be used as reliable electric power. The remaining portion of the power can be used to produce hydrogen or to store energy in batteries for transportation purposes without pollution [203]. This review shows that clean hydrogen can be economically produced from renewable energy resources. It will be useful to design, construction and operation of wind-powered hydrogen production plant in different countries.

9. Wind energy feed-in tariff

The FIT is the most effective policy mechanism that a country uses to accelerate the rapid development of Renewable Energy (RE) systems and it provides a long-term and stable market for manufacturers and developers of RE technologies. It is a minimum guaranteed price to be paid to the producer of the RE electricity per unit. It summarizes the feed-in tariff mechanisms and wind energy Feed-in Tariff (FIT) rates of different countries.

Wilson Rickerson et al. (2012) explained the FIT policy issues to support the development of local capacity and provided advice to developing countries in designing and implementing nationally appropriate FIT frameworks. The most prevalent RE policy in the world is the FIT. As of early 2011, fifty countries had some form of Feed-in Tariffs (FITs) which have been used and analyzed in many developing countries [204]. Bradley Motl (2011) mentioned that the different forms of FITs exist throughout the world. On September 15, 2009 the Vermont Public Service Board issued an interim FIT rate order, which set the rate of return on equity at 12.13 percent [205]. Toby Couture et al.(2010) provides a detailed analysis of FIT payment design options, FIT implementation options, and various mechanisms to identify a set of best practices that have been effectively stimulating the deployment of large amounts of RE generation. There are four main approaches such as the levelized cost of RE generation, value of the RE generation, fixed-price incentive and auction-based mechanisms used to set the overall FIT payment to RE developers [206]. Toby Couture and Yves Gagnon (2010) examined and presented an overview of seven different models to structure the remuneration of FIT policy for electricity generated from RE sources [207]. The Energy Resource Institute (TERI) Report to Central Electricity Regulation Commission (CERC) on pricing of power from non-conventional energy sources (2008) has discussed and explained an alternative approaches such as cost-based approach and marginal cost/avoided cost based approach FIT determination. The critical parameters for FIT variation are capital cost, operation and maintenance expenses, return on equity and capacity utilization factor [208].

Stavroula Petsa (2010) evaluated the effects of capacity factor, discount rate, exchange rate and capital cost on required FIT level for wind installation in South Africa. These parameter variations have a strong impact on the required FIT Level for wind energy technologies. He also reviewed different methodologies such as discounted cash flow approach, levelized cost of electricity, NPV calculation methodology, and inclusion of taxes and excel spreadsheet model to calculate FIT [209]. Sibusisoz (2011) reviewed wind energy FITs to achieve the efficient, effective and sustainable development of wind energy in South Africa. The qualifying wind energywhich is more than or equal to one MW capacity FIT was reviewed as R 1.25/kWh and R 0.938/kWh in 2009 and 2011 respectively based on Levelized cost of Energy (LCOE) methodology [210]. Josef Auer (2012) analyzed the German FIT of wind energy technology. The FIT policy has delivered transparency, longevity, and certainty to investors in German wind energy projects. The initial FIT rate available for onshore wind energy declined annually under a degression schedule between 2004 and 2008. Starting in 2009, the initial rate increased to 9.2 € cents/kWh. Repowered wind sites were eligible for an additional 0.5 € cents/kWh during the period of the higher initial payment. Germany has the most successful FIT program in the world [211].

Graffagna and Mizutani (2011) outlined Japan's FIT Law to encourage new investments in wind electricity generation. Under Procurement of Renewable Electric Energy by Operators of Electric Utilities Act, Japanese electric utility operators are obligated to purchase wind generated electricity for contractual terms and at prices to be fixed by the Minister of Economy, Trade and Industry (“METI”) [212]. Berger and Kabat (2010) analyzed New York's FIT methodologies and presented several issues to promote wind energy development. New York State is one among several states to have considered FIT legislation. Tariff rates vary from state to state. Most of the states have considered FIT programs based on an

avoided cost model. FITs have recently gained popularity in the United States as policy mechanisms [213]. Peters and Weis (2008) compiled the benefits, elements of a good FIT problems and status of FITs across the world. Close to two-thirds of the world's wind energy system has been installed as a result of FITs. The "feed-in mechanisms achieve larger deployment at lower costs" than other policy mechanisms such as quotas, direct incentives or voluntary goals. By the end of 2006, close to 45,000 MW of wind power was installed through feed-in tariff mechanisms on continental Europe – almost four times that of North America. Ontario's Standard Offer Contract program is the first program to use some form of FITs in North America [214]. Ragwitz et al. (2012) prepared a report on recent developments of FITs in the European countries. In 1990 Germany was the first European country to introduce a FIT [215].

Winkel et al. (2011) analyzed the renewable energy FIT in European countries. The main promotional instrument to support energy from Renewable Electricity Standard (RES) in Austria is a FIT system offering technology-specific incentives with purchase obligation. The guaranteed duration of the FIT is currently 13 years for wind technology. FITs for electricity from wind power in Austria is €cent 9.7/kWh. The key support instruments in Cyprus are direct subsidies. The FIT for wind energy grid connected installations up to 165 MW for the period 2011 was €166/MWh. In the Czech Republic, the generation of Renewable Electricity Standard for Europe (RES-E) is promoted primarily through a price-regulation. It is managed by the energy regulatory office. The FIT for wind energy technology started in 2011 was € 75.54/MWh. The key policy instrument for support of RES-E in Spain is based on a special remuneration scheme in which producers may choose between a FITand a feed-in premium. The regulated tariff for on shore wind energy for the first 20 years is €cent 7.9084 per kWh. The current RES-E support scheme cause in-to effect from12th July 2009 by the adopted amendment of the law on energy in Slovenia. The FIT for wind energy plant up to 5 MW in 2011 was € 95.38 per MWh. Since 2005, Slovakia has had a FIT in place, based on the Law on Energy. The fixed tariff was determined on the basis of installed capacity and the date of commissioning the plant for wind energy technology. The wind energy FIT was determined as € 80.91 per MWh. The RES-E support instruments in Denmark were amended in 2008. Denmark promotes RES-E through a price regulation. Guaranteed price premium of 33.5 €/MWh was paid for 22,000 full load hours operation. Additionally, 3.1 €/MWh is received during the entire lifetime of the turbine to compensate for the cost of balancing. The FIT for household wind turbines below 25 kW capacities is € 80.6 per MWh in Denmark. In Finland the main support instrument for RES-E is now a feed-in premium. The target price for electricity production as part of the feed-in premium scheme for wind power plants is 83.50 €/MWh. The main instrument for the promotion of RES-E in Greece is a feed-in tariff. The wind energy exploited through land facilities with capacity greater than 50 kW interconnected system received a FIT of € 87.5 per MWh in 2011. Hungary wind plants have received FIT of € 0.102 per MWh for 0–50 MW capacities since 2010. The FIT scheme in Ireland was launched in May 2006 and it is managed by the Department of Communications, Energy and Natural Resources. In 2011, the FIT for on-shore wind plant for more than 5 MW installed capacities received € cents 6.6 per kWh. The Italian system of on-shore wind energy FIT based on Tradable Green Certificates is € 220 per MWh for more than one MW capacities. FIT is the main instrument currently used in Latvia. The FIT system is implemented in accordance with regulations and price setting. The wind energy FIT has ranged from 68.14 to105.62 €/MWh for the first 10 years and 40.88 to 63.37 €/MWh for 10 years after. Lithuania has a FIT and a purchase obligation for electricity produced from wind energy sources. FITs will be differentiated by technology, the installed capacity, the meteorological data and the power plant location. The wind energy FIT level in Lithuania since 1st January 2009 to 2011 has been € 86.9 per MWh. The main support instrument for RE development was feed-in tariff in Luxembourg and it was introduced in 1993 and amended in February 2008. The Ministry of Economy and Foreign Trade is in charge of implementing and executing the law. A feed-in tariff for wind energy in 2008 until 2012 was € 81.9 per MWh. Portugal FITs are available for wind energy producers with tendering schemes. The scheme is commonly known as "Tarifa Verde", or green tariff. The indicative average tariff for wind energy is € 74–75 per MWh for 15 years [216].

Jon litly et. al (2010) briefly reviewed the evolution and status of various feed-in-tariff of off-shore wind energy programs throughout Europe and North America. Several European countries have experienced unprecedented growth in generation and industry after the adoption of feed-in tariffs. Current rates for off-shore wind energy in Germany are set at €¢13/kWh with a €¢ 2/kWh bonus if the project is in service by 2013. The standard rate for offshore wind projects is 13 €¢ / kWh with project lengths ranging from 1–10 years in France [217]. The Public Utilities Commission (PUC) of Sri Lanka (2011) calculated wind energy electricity purchase tariff based on projected cash flow of a generic one MW plant over 20 years. The parameters used for tariff revision are capital cost, plant factor, operation and maintenance cost. The methodology for wind energy purchase tariff is approved by the PUC of Sri Lanka in terms of Section 43 of Sri Lanka Electricity Act, No 20 of 2009 [218]. Karin Corfee et al. (2010) presented FIT for California. California has been actively investigating feed-in tariffs during the past several years as a policy mechanism that could help the state achieve its goal of 33 percent renewable electricity by 2020. The Competitive Renewable Energy Zones (CREZs) in California has three groups of FIT rates, such as equal premium, diversified and cost minimizing policies. The wind energy FIT under equal premium, diversified and cost minimizing policies in California are $ 137.00, $ 143.00 and $ 125.00 per MWh respectively. The French feed-in tariff is based on generation cost and uses a flat, fixed rate, similar to Germany's, with contract lengths that range from 15 to 20 years. In 2009, the on-shore wind energy FIT for Netherland, and French were 9.4[€ct/kWh] and 8.20 c€/kWh respectively [219].

David Jacobs and Freie Universitat Berlin of Environmental Policy Research Centre has compiled report on assessment of the proposed feed-in tariff mechanisms for Malaysia for four renewable energy technologies such as biogas, biomass, small hydro and solar PV using a cost-based tariff calculation methodology for 2011 [220]. The Handbook on the Malaysian feed-in tariff for the promotion of renewable energy (2011) reported that the wind energy technology will not be offered under the FIT as the technical potential of wind energy resource has not to be determined in Malaysia [221]. Gabriela Elizondo Azuela et al. (2011) explained the emerging experiences in selected developing countries. The United States implemented its first FIT Policy (FITP) known as the Public Utility Policies Regulatory Act (PURPA) in 1978 and also implemented a quota mechanism known as Renewable Portfolio Standard (RPS) since 1983. The United Kingdom also introduced an FITP for RE projects for the capacities lower than 5 MW in 2010. FIT Policies (FITPs) have been particularly effective in India. The FITPs are more effective at lowering investors' risks than RPS or quota instruments. The effectiveness of FITPs seems to be strongly linked to the existence of fiscal and financial incentives. In India on-shore wind energy FIT based on CERC levelized tariff 2010-2011 was in the range of 7.4–11.05(USD cents/kWh). In the Indian States like Maharashtra and Gujarat, the FITs have been 9.92 (USD cents/kWh) and 7.76 (USD cents/kWh) respectively for 25 years. India uses three RE policy instruments like auction, FIT

and, renewable energy certificate market. The different fixed FITs types included are stepped tariffs, tariffs with degression rates, and flat tariffs [222]. A more detailed analysis of FIT impacts will help decision makers to understand the FIT policy implementations. Feed -in tariffs appear to be one of the best mechanisms for quickly creating wind energy installed capacity.

10. Modeling techniques on wind turbine components

The dynamic characteristics of WTG systems, model analyses on wind turbine components and optimization of wind farms have been reviewed as follows: Zhou and Wu (2010) established the model of helical gear of WTG by using three-dimensional modeling software PRO/E, and through data exchange interface. The model was converted into ANSYS, the model analysis was carried out and then the low natural vibration frequencies and vibration mode were obtained to improve the smooth and reliability of the driven system. This also improves the design efficiency of helical gear. This is the basis for the design and optimization of the gear transmission system to improve the performance of WTGs [223]. Bir.G. (2010) described a model analysis code for the blades and tower of a wind turbine, using a finite-element code. The verifications were performed by comparing B-Modes-generated modes with analytical results. All results in general showed excellent agreement with analytical work [224]. Frankenstein et al. (2009) performed a model monitoring of wind turbine rotor blades using operational model analysis method and global model methods combined with FEM simulation. The results indicated that the different wave modes interact distinctively with inner structural damages such as web fractures and delaminations, and the combination of both methods allowed an effective monitoring of the global structure [225].

Miao et al. (2009) conducted a model analysis using ANSYS software in design of wind turbine to ensure and secure operation of wind turbine. The result indicated that the inherent frequency of wind turbine did not coincide with the excitation frequency of rotor, and the system could operate steadily in the design condition [226]. Johnston et al. (1998) performed model analysis of preloaded wind turbine structural components. The wind turbines were subject to a large horizontal force during normal generation of electricity due primarily to axial thrust on the power train [227]. Babypriya and Anita (2009) analyzed the steady state characteristics of a WTGS with doubly fed induction generator (DFIG) and developed the dynamic steady-state simulation model of the DFIG using MATLAB and performed simulation analysis to investigate operating characteristics of DFIG [228]. Kabalci et al. (2011) modeled an AC–DC–AC converter for wind turbines using Simulink simulation and analyzed a controlled rectifier which minimized the harmonic contents for the designed system [229]. Akhmatov et al. (2003) implemented a physical model and short-term voltage stability of large wind farms using dynamic simulation tool PSS/E. The stability was improved on the wind farm side of the grid connection point. This leads to significant reduction of dynamic reactive compensation demands [230]. Anderson and Bose (1983) described the stability simulation model of wind turbine systems and studied the important parameters of the wind speed [231].

Mosetti et al. (1994) presented a novel approach to the optimization of large wind farms using wind farm simulation model based on wake superposition with a genetic search code. A square site subdivided into 100 square cells as possible turbine locations has been considered for the optimization with the number and position of the turbines for three wind cases. The wind turbine distribution at a given site was optimized in order to extract the maximum energy for the minimum installation costs [232]. Long et al. (2010) analyzed the dynamic characteristics and vibration response of gear driven system of wind turbine using model parameters to calculate meshing stiffness, damp coefficient and error excitation and using 4-steps Runge-Kutta method with MATLAB software [233]. He. et al. (2009) investigated the dynamic performance of a wind turbine system under earthquake condition. The effect of the soil-structure interactions were identified using the physical stochastic model and an integrated finite element model [234]. Schlecht and Gutt (2002) studied the dynamic behavior of the wind turbine drive train by using the multi-body system simulation to reduce the need of risky and expensive measurements. The MW power output WTGs requires a very good knowledge of the dynamic loads of all possible operational situations for dimensioning of wind turbines to meet their expected operation loading [235]. Rmmert Dekker (1996) highlighted the reliable maintenance optimization model to ensure reliable maintenance of WTGs. The maintenance actions will only be effective and efficient if the most relevant deterioration and failure mechanisms are addressed specifically [236]. Iniyan and Jagadeesan, (1997) presented a comparative study of critical factors influencing the renewable energy systems in the Indian context using Delphi technique. The social acceptance factor was ascertained for different RE end-uses [237]. Theses reviews on modeling will be useful to design and improve the efficiency of wind farms located in different part of the world.

11. Performance prediction and improvement techniques of WTGs

The prediction of operational performance, performance optimization and repowering of WTGS, comparisons and selection of suitable WTGs, capacity factor evaluations and reliability model analysis on wind farms have been reviewed as follows: Ackerman and Soder (2000) compared torque coefficients and corresponding power coefficients with tip speed ratio of wind turbine. The torque coefficient showed a nearly linear decrease as the tip speed ratio increases [238]. Lanzafame and Messina (2009) considered how to determine the laws which govern to twist the blades to maximize electrical energy output from the two bladed WTG, with a 10 m diameter in a given wind site using ‘blade element momentum theory. They also compared two different methods of blade design for maximizing the power coefficient. Determining the best geometric parameters for the blade of a wind turbine is critical for maximizing energy production [239]. Griffiths (1978) analyzed the performance of a typical wind turbine to give maximum power coefficient at a tip speed ratio of 5 over a range of speed ratios and pitch angles using blade element theory [240]. Pope et al. (2011) presented a new model to predict the operating performance of a Vertical Axis Wind Turbine (VAWT) and developed a power coefficient correlation for a novel VAWT called a Zephyr VAWT [241]. Pablo del Rio (2010) analyzed the interactions between energy efficiency measures and renewable energy promotion to identify positive and negative interactions between them [242]. Lissaman (1979) calculated the wind farm efficiency for a specific wind speed. The ratio of the entire power generated by the real farm to the one corresponding to all wind turbines operating in the absence of wake effects is the wind farm efficiency. The wind farm efficiency is a function of the turbine type employed, the wind farm configuration and wind speed. Estimation of the overall efficiency of a wind farm is of crucial importance to a wind farm design procedure [243]. Kiranoudis and Maroulis (1997) studied an effective short-cut modeling of wind park efficiency using 11 parameters for all types of turbines [244].

Heping Zou et al. (2007) investigated the performance of the wind turbines with DFIG during a voltage dip caused by an

external short circuit fault and compared the variable speed wind turbines with fixed speed wind turbines. The variable speed generators include improved power quality, speed control, reduced mechanical stresses, decoupled control of active and reactive power as well as more power generation than fixed speed generator under the same circumstances [245]. Kentfield and Brophy (1997) predicted the performance of Cierva-rotor wind turbines. It was found from the analysis that it was possible to reduce tower bending moments relative to a conventional horizontal axis turbine of equal power output, equal maximum hub heights and blade tip altitudes. The Cierva turbine was capable to produce greater power output than a conventional horizontal axis WTG at a prescribed wind speed. For example a Cierva rotor 56% greater in diameter than an otherwise comparable conventional horizontal axis rotor of equal solidity has a maximum output approximately 100% greater close to the cut in wind speed of 4 m/s dropping to about 50% greater at 12 m/s [246]. Dragomirescu (2011) designed a vertical axis Savonius type wind turbine to harvest wind power at a low wind speed and estimated performance with cross flow runner by numerical simulations. The results obtained suggest that this turbine has a considerable high starting torque and its maximum power coefficient of about 0.45, is comparable to those of horizontal axis wind turbines [247].

Wright and Wood (2004) presented the low wind speed behavior of a small Horizontal Axis Wind Turbine (HAWT). A small, three-bladed HAWT can start at a wind speed of about 4.6 m/s on average. Vertical axis wind turbines (VAWT) of Savonius type can start at lower wind speeds, down to about 2 m/s, but they have a poor efficiency, the power coefficient, c_p, being less than 0.25 [248]. Yoshida (2006) compared the performance of downwind-turbines with upwind-turbines in complex terrain. The result showed that the 2 MW downwind-turbines produced 7.6% more annual energy than upwind-turbines with same dimensions [249]. Lewis and Cheng (1980) developed a momentum control volume analysis for predicting the performance of HAWT of prescribed geometry and of known profile aerodynamics. It predicted the influence of air brakes upon the system characteristic, and makes it possible to compute characteristics with variable pitch control applied to the whole blade or parts of it. A design method was also presented for the selection of blade geometry to suit prescribed radial distribution of blade loading [250]. Nagai et al. (2009) described the performance of a 3 kW wind turbine generator with variable pitch control system. The wind turbine showed a power coefficient of 0.257 under the average wind speed of 7.3 m/s [251].

Novak et al. (1995) described the best approach to evaluate the aerodynamic torque uses dimensionless coefficients C_p and C_q, which respectively express the variable speed wind turbine ability to convert kinetic energy of moving air into mechanical power or torque. The static converter is used as the interface between the generator and the electrical load. The generator torque is perfectly adjustable in all operating bandwidth and virtually independent from WTGs dynamics [252]. Chen et al. (2009) predicted the performance of wind turbine airfoil for large wind turbine by interactive viscous-in viscid approach and computational fluid dynamics method with different turbulence models. The wind tunnel test was conducted to validate predicted results. It was found that the airfoil performance was degraded by leading edge roughness of wind turbine blades [253]. Sorensen (2011) reviewed the most important aerodynamic of WTGS and discussed the modeling and prediction of aerodynamic forces, such as performance predictions of wind farms, and the design of specific parts of wind turbines, such as rotor-blade geometry and also reviewed wind turbine rotors and wakes using advanced numerical simulation in wind farms [254].

Boccard (2009) estimated the mean capacity factor of wind power plants ranged from 30% to 45% between 1998 and 2008 in European countries [255]. Sasi and Basu (1997) studied the capacity factor and selection of size of wind electric generators based on Indian sites. It concluded that for every wind regime there is an optimum value of the rated wind speed of the WEG to be installed at the site that maximizes the WTG output on an annual basis. The annual levelized cost of energy for WTG operation at a site varies with the wind speed rating of the machine and the least cost occurs when the machine is rated at a wind speed which may be less than or equal to optimum rated wind speed of a WTG depending on the site characteristics and the machine cost [256]. Takagi et al. (2010) investigated the navigation logic to improve the capacity factor and performed a fatigue assessment of very large mobile offshore structure (VLMOS) for wind power generation to ensure the structural safety of light weight design and to create a new backbone of energy resource. Navigation simulations showed that it was easy to achieve more than 40% capacity factor. It is stated that the structure has enough fatigue strength for a 100 years of operation even if wind turbines get more than 40% of the capacity factor [257]. Jangamshetti and Rau (2001) explained the normalized power curves as a tool for identification of optimum wind turbine generator parameters and reported overall efficiency of 35%. The *WTG* parameters were determined at the maximum value of the product of normalized average output power and capacity factor [258]. Lindley and Gamble (1988) analyzed the construction and operational performance of a 5 MW wind farm installed at a site near Ilfracombe in Devon in the U.K. This wind farm had generated over 10 million - kilowatt hours. with an availability of 95% and a capacity factor of 31% with nine months of it operation [259].

Iniyan et al. (1996) evaluated the performance of wind turbine generators for the largest demonstration wind farm (10 MW) in Asia and calculated the technical availability, real availability, capacity factor and the maximum down time of the wind turbine generators and identified 30 fault conditions and analyzed by pareto diagram [260]. Iniyan and Jagadeesan (1998) developed an Optimal Renewable Energy Model (OREM) to determine the optimum level of renewable energy sources utilization in India for the year 2020–21 and analyzed the 4 MW demonstration wind farm which was situated in Muppandal, a village in the southern part of India. The average technical availability, real availability and capacity factors were found to be 94.1%, 76.4% and 25.5% respectively [261]. Iniyan et al. (1998) carried out a critical analysis on wind farms to improve the performance and reliability of 6 MW demonstration wind farm. They determined the average technical availability, real availability and capacity factor were 92%, 54% and 19% respectively. The failure rate was high to an extent of $6.7 \times 10^{-5}\ h^{-1}$ in the case of a yaw control defect and the factor of reliability was found to be 0.5 at 10 000 h. The analysis revealed that when the reliability factor of wind energy system was improved from 0.5 to 0.9, the utilization of wind energy increased by 82% [262]. Albadi and El.Saadany (2009) presented the wind turbine capacity factor modeling using wind speed characteristics at any site and the turbine power curve parameters for optimum turbine-site matching [263].

Coxon (2004) estimated cut-in and shut-down wind speed for a grid connected wind turbine. Unnecessary cut-in reduces net power generation. Development of the control system of the grid connected Gazelle wind turbine highlighted a problem when values of the measured local wind speed were used to disconnect and reconnect the turbine. The measured wind speed at shut down was less than when the blades were stationary, as related to the induction factor [264].

Palutikof et al. (1990) simulated the effects of geographical dispersion on wind turbine performance in England, using hourly wind data on four widely dispersed sites in England and identified output changes by 50% [265]. Symanski et al. (1983) observed and

monitored the first year operating experience and performance characteristics of a pilot wind farm consists of twenty windmills located on Crotched Mt. in Greenfield, New Hampshire.The WTGs are independently controlled, monitored and supervised by a central microcomputer [266]. Habash et al. (2010) conducted the performance optimization test on a dual-rotor wind turbine system using wind tunnel experiment. The wind tunnel test indicates that a scaled-down version of the dual-rotor turbine system may produce up to 60% more power than a single-rotor system [267]. Habash et al. (2011) experimentally verified the performance of a small wind energy converter (SWEC) and also discussed issues related to control and monitoring of SWEC. The wind tunnel tests of the power output, power coefficient, and turbine speed were carried out to ascertain the aerodynamic power conversion and the operation capability at lower wind speeds. The results demonstrated a significant increase in performance compared to a single-rotor system of the same type [268]. Pablo del Rio (2011) provided an overview and a qualitative analysis of instruments and design options to support repowering of on-shore wind farms. Repowering of a wind farm is the process of replacing existing wind turbines with new turbines that either have a larger name plate capacity or more efficiency, resulting in a net increase of the power generated [269]. Sasi and Basu (2002) analyzed the performance of wind farm in India and suggested steps to be adopted by the government agencies in order to ensure the desired growth of the wind industry in the country and also presented the wind farm development policy in India [270]. Kaigui Xie and Roy Billinton (2011) introduced an equivalent capacity ratio design for WTG system to evaluate the energy production and the relative reliability performance and it also used to assist in the determination of the optimal WTG type for a specific wind site [271].

Milborrow (1980) explained the performance of arrays in wind turbines to design reliable and cost-effective wind farms capable of large-scale electrical energy production. The determination of type, number and layout of wind turbines should maximize the energy output together with the lifetime of the machines [272]. Afgan and Cvetinovic (2010) presented the wind power resilience index monitoring using following indicators, namely: average wind velocity, power production, efficiency of electricity production, and power-frequency change. Resilience of the wind power plant is the capacity of the system to withstand changes. The performance of the wind power plant depends on the wind kinetic energy. It depends on the number of design parameter of the wind turbine. For the wind power plant the wind kinetic energy conversion depends on the average wind velocity, mechanical energy conversion into electricity, and electricity transmission [273]. Negra et al. (2006) evaluated the HVDC transmission losses for wind systems and found that the converter station losses were 1.4–1.6% of the annual output of the connected wind farm [274]. Dobakhshari and Fotuhi-Firuzabad (2009) used several approaches to model wind power output ranging from chronological simulation to probabilistic methods. A reliable wind power output modeling is critical in determining its correlation with market prices to estimate the capacity credits of wind power [275]. Carta et al. (2008) used the Weibull distribution to model the wind speed. A probabilistic model was obtained for the wind power by transforming the wind speed into electric power through the power curve of a turbine [276].

Karki et al. (2006) proposed a simplified normal wind speed model to evaluate the reliability of a power system containing WTGS. This result indicated that the normal wind speed model can be used to simulate a wind speed time series with a higher accuracy [277]. Basset et al. (2010) presented the vibration analysis of a 2.3 MW wind turbine operation using discrete wavelet transform technique to improve the reliability of commercial wind [278]. Govil (1983) explained the reliability properties for the systems. The prediction of system reliability is based on life characteristics. The life length can be measured by Mean Time Between Failures (MTBF). During the operating period, when failure rate (λ) is fairly constant, the MTBF is the reciprocal of the constant failure rate [279]. Srinath (1991) determined the reliability of the system using exponential distribution based on mean time between failures. When a system is often unavailable owing to breakdowns and is put back into operation after each breakdown, the mean time between breakdowns is defined as the MTBF. The larger the MTBF, the higher is the reliability of the system [280]. Billinton and Bai (2004) had done case studies on wind energy and the results showed that the WTG cut-in and rated wind speeds had a significant effect on the reliability of a power system and the cut-out wind speed had almost no effect [281].

Giorsetto and Utsurogi (1983) developed a new procedure for reliability modeling of wind turbine generators and determined a nonlinear relationship between the wind turbine power output and the wind speed. A WTG is designed to start generate power at the cut-in speed V_{ci} and is shut down for safety reasons if the wind velocity is higher than the cut-out speed V_{co}. In both cases, the power output is zero. The power output of a WTG unit increases with the wind speed between the cut-in speed and the rated speed V_r; after that the power output remains constant at the rated power P_r [282]. Chowdhury (2005) developed reliability models for large wind farms in generation system planning and measured power curves for WTG [283]. Billinton et al. (1996) developed time-series models for reliability evaluation of wind power systems to determine the necessary parameters of the wind speed model for a specific site. This wind speed time series usually modeled by many distributions, including Weibull distribution and normal distribution [284]. Xie and Billiton (2011) presented an approach to determine the optimum installation design at each wind site considering the WTG parameters, the total cost of WTGS and the power system reliability performance using a genetic algorithm model. The proposed approach can be used to obtain the maximum economic and reliability benefits associated with a WTGS installation and are a powerful search technique for determining the optimum number and type of WTG considering reliability performance and costs. The economic and reliability benefits of adding a WTGS to a power system are highly dependent on the wind turbine generator (WTG) installation design, i.e., the type and number of WTG [285]. Billinton and Bagen (2004) incorporated the reliability index distributions in small isolated WTG system. The power system reliability indices of loss of load expectation and the loss of energy expectation decrease somewhat exponentially with the number of WTG units added to the system, but tend to saturate when wind speeds continue to increase. The forced outage rate of the WTG has relatively little impact on the reliability performance of a power system [286].

Nam et al. (2011) introduced a methodology for the power control of a wind turbine, which is the Variable-Speed and Variable-Pitch (VSVP) control system and also discussed some simulation results for the VSVP control to a MW wind turbine. This control methodology maximizes the capability of the turbine to extract maximum power from the wind in the regions with low wind speeds. Further, it regulates the wind-turbine power as the rated power in the case of the regions with high wind speeds [287]. Hock Susan etal. (1990) presented two basic design philosophies of wind turbine system. The first represents a system using power electronics to allow variable speed operation and the second represents an optimized stall-controlled rotor. The investigation indicated that these design improvements increased energy capture about 40% to 50% with a corresponding negligible impact on cost, when compared with current state-of-the-art

Table 1
Renewable energy technologies (RET) costs.

Sl. no.	RET	Cost $/kW
1	Small hydro	4.000
2	Biomass	2.500
3	Geothermal	4.000
4	Wind on-shore	2.000
5	Solar P.V (Utility)	3.500
6	Solar thermal with storage	11.000

wind systems. These performance improvements resulted in cost of energy estimates ranging between $0.03 and $0.06/kWh for the mid-1990s for sites with annual average hub-height wind speeds from 8.5 m/s to 6.8 m/s [288]. These reviews on performance of wind farms will be useful to predict and efficiency improvement of wind farms.

12. Cost and economic of wind energy production

The cost reduction potential of the wind turbines yet to be explored is one central problems of future economics. A specific economic calculation of an investment project is realistic with the conditions of financing. The following articles have been reviewed from the cost and economic point of view of wind energy production. The International Renewable Energy Agency (IRENA) estimated the costs of different renewable energy technologies by using the most influential parameters such as investment and operational costs, full load hours, fuel price (in the case of biomass), interest rate, expected return on equity and electricity price that are given in Table 1.

The cost for wind on-shore is $ 2.5 per kW which is comparatively low among other RET [289]. The International Renewable Energy Agency (IRENA) (2012) reported wind energy cost analysis. The installed costs in 2010 for onshore wind farms were as low as USD 1300 to USD 1400/kW in China and Denmark. The O & M costs for wind farms in major wind markets average between USD 0.01/kWh and USD 0.025/kWh. In India cost of installation of onshore wind farm was USD 1460 /kW in 2010. The estimated cost of wind power varies significantly depending on the capacity factor, which in turn depends on the quality of wind resource and the technical characteristics of the wind turbines. Assuming a capacity factor of 25% for new project, the LCOE of wind in China and India was between USD 0.07 and USD 0.08/kWh in 2011. The LCOE of off-shore in wind is around twice that of onshore wind for a given C.F in Europe and North America. The discount rate also has impact on LCOE. The LCOE was 6.65 US Cents/kWh at 5.5% discount rate where as it was 16.05 US Cent/kWh at 14.5% discount rate for a particular wind power projects of 25% C.F in the United States [290]. Karlynn Cory (2009) prescribed the renewable energy FIT of the United States in the National Renewable Energy Laboratory Technical Report. There are a few locations where the cost of wind power development is in the range of $0.05–0.07/kWh in the United States [291].

Wu and Cai (2010) analyzed an economic dispatching of renewable energy distribution generation system using mathematical models. The simulation results showed the correctness and validity of the models and algorithms [292]. Akdag and Guler (2010) performed wind electricity generation cost analyses at 14 locations in Turkey to motivate the interest in wind energy investment. Capacity factors of investigated locations were calculated between 19.7% and 56.8%, and the production cost of electrical energy was between $cent 1.73 and $cent 4.99 per kW h for two different wind shear coefficients [293]. Norberto Fueyo et al. (2011) presented the use of cost-generation curves for the analysis of wind electricity cost in Spain to determine the uncertainty in the costs of the several model parameters from onshore wind farm. This also related the energy cost to the land occupancy, the installed power and the capacity factor and it was established for an electricity-generation level of 300 TW h/y and the specific marginal cost was 8.5 c€/kW h [294]. Blanco (2009) offered a comprehensive survey of the factors that influence the cost estimates for onshore and offshore wind farm in Spain. The generating cost for a typical wind farm operating between 1700 and 3000 full-power-equivalent hours (equal to a capacity factor between 19% and 35%), was in the range 4.5–8.7 c€/kW h. The capital costs in her study were found to vary between €1100–€1400/kW onshore and €1800–€2500/kW offshore. The price of offshore capacity is expected to fall faster to enable higher efficiency of larger turbines [295].

Ortega Vazquez and Kirschen (2010) presented a methodology for quantifying fully the effect of wind power generation on the various components of the cost of operating the system. While its low marginal operating cost reduces the overall cost of meeting the demand for electrical energy, the stochastic and intermittent nature of wind generation increases the uncertainty that the system operators face [296]. Frias et al. (2010) analyzed both investment and operating costs and also computed the wind power intermittency and predictability errors in Spanish power system [297]. Morgan (2003) estimated the monitoring and general control cost as a value of 41 k€ per turbine of 2.3 to3.6 MW size and estimated the project development cost as 45.6 k€/MW for a 100 MW wind farm [298]. Johnson and Solomon (2010) analyzed a net-present value analysis for a 1.65 MW Vestas wind turbine at a small college in the US. The purchase, transport, and installation cost was $ 3.4 million at $2060/kW [299]. Ichita et al. (2010) presented a method to calculate each cost of WTGS component such as drive train system, generator and other equipments, and also to evaluate generation cost obtained from WTGS cost and annual electrical energy production. The wind turbine generator output and annual energy production are dependent on wind characteristic of each area and a kind of WTGS. Based on these results, the optimal kind of WTGS was determined for each installation area from an economical point of view [300].

Bresesti et al. (2007) assumed that converter losses are 1.8% at full power and estimated that converters cost 0.11 million Euros per MW, or about $430 million for a 3000-MW system. The converter station includes converters, transformers, filters, smoothers, and auxiliary and protection equipment [301]. Cavallo (2007) studied the controllable and affordable utility-scale electricity from intermittent wind resources and compressed air energy storage and estimated the transmission cost and the cost of compressed air storage as $0.05–0.06/kWh [302]. De Carolis and Keith (2006) analyzed the economics of large-scale wind power in a carbon constrained world and estimated the cost of long-distance transmission, and back-up as $0.05/kWh [303]. Ahmed R. Abul'Wafa (2011) presented a probabilistic method to evaluate the contribution of a wind power delivery system to the overall system reliability and environmental improvement and determined appropriate transmission line capacity based on the overall system risk and associated transmission system cost [304]. Hoppock et al.(2010) suggested comparison of potential wind resources to meet a state RPS and compared cost of local wind ($\sim$50 km from the load) to the cost of distant wind($\sim$550–750 km from the load) to meet the Illinois RPS. They found that the local wind resource was the lowest cost option to meet the Illinois RPS. The new long distance transmission was required to access distant wind resources [305].

Sioshansi (2010) evaluated the impact of real-time pricing on the cost and simulated a real-time pricing mechanism to reduce

the re-dispatch cost and loss of load events and to assess the effects of wind power on market prices [306]. Jose and Pahwa (2010) focused an economical evaluation of small wind energy generation and shown comparison of the Critical Peak Pricing (CPP) and Time of Use (TOU) schemes with the fixed existing rate to help utilities and to consumers to decide the best pricing scheme [307]. Jorge Valenzuela and Jianhui Wang (2011) evaluated the economics of wind energy by developing a probabilistic model to compute the long-term probability distribution of market clearing prices and wind farm revenues. Understanding the long-term economic impact of wind energy on electricity markets is becoming more important owing to the increasing penetration of wind power in the generation mix of power systems [308]. Jacobson and Masters (2001) compared the unsubsidized costs of land-based wind energy to the costs of a new coal-fired power plant and found that it was similar [309]. Munksgaard and Morthorst (2008) assess how an increased level of wind penetration will affect wholesale market prices in Denmark. The study found that increase in wind capacity leads to lower prices reducing the average demand from thermal power generation [310].

Van den Doel and Van Gemert (1988) discussed the economic feasibility of wind farms in Holland and presented the methods to select low cost locations and to make optimal wind farm siting [311]. Shafiqur Rehman et al. (2011) presented the design and economic assessment of a wind farm of 20 MW installed capacity located in the Eastern region of Saudi Arabia using wind farm software and obtained the energy yield and the wake losses were obtained for the wind farm. The proposed wind farm could generate 59037.7 MW h of electricity annually with plant capacity factor of 33.7%, excluding the wake losses of 3.48% and could produced the energy at US¢ 2.94 per kW h [312]. Bastian and Trainor (2010) had done cost-benefit analysis of 12.5 MW wind farm for electricity production of the United States Military Academy (USMA) at West Point, NY. This brought educational, strategic, and potentially economic benefits to USMA, in addition to the obvious environmental benefits realized by the Hudson Valley region [313]. Sinha (1994) described optimization model in unit cost of renewable energy and estimated the cost of solar thermal electric conversion and solar photovoltaic electric conversion were Rs. 11.92/kWhr and Rs. 11.70/kWhr respectively [314].

Richard Green and Nicholas Vasilakos (2011) reviewed the various support policies associated with the economics of offshore wind technology used in Europe Denmark. Offshore wind suffers from high installation and connection costs, however, making government support is essential [315]. Umashankar et al. (2011) optimized cost effective fully fed wind turbine High Temperature Superconductivity (HTS) generator replacing the existing one in offshore wind farms to bring manufacturing & maintenance costs down and to eliminate the gearbox problems which will increase reliability which is of utmost importance for remote and offshore farms [316]. Markard and Petersen (2009) analyzed the feed-in tariff of off-shore and onshore wind farms in Denmark and Germany. Under a feed-in tariff, the policy-maker sets a fixed price which is paid for every qualifying unit of electricity [317]. These reviews will be useful to do economic analysis of any wind farm. The energy supply for any country has high significance for its economy and social life.

13. Generators influences on wind energy production

The simulation models and control strategies, grid interface and smooth operations strategies of synchronous generators as well as double fed induction generators have been reviewed as follows: Abedini and Nasiri (2007) developed and simulated the model of a PM Synchronous Generators (PMSG) wind turbine to evaluate the performance of the system during short circuit fault and developed two methods for controlling the converter. A new protection method for capacitor over voltage was also evaluated. The PMSG offers better performance owing to higher efficiency and less maintenance since they do not have rotor current and could be used without a gear box [318]. Polinder et al. (2009) reviewed fault tolerance in generator systems for wind turbines and reviewed of wind turbines, electrical machines and power electronic converters of wind turbines. The converters failed more often than machines, it made sense to use of fault tolerant converter topologies. Increasing the number of phases is a useful form of fault tolerance because it can be achieved without increasing the cost significantly [319]. Zhang et al. (2011) proposed a robust and reliable grid power interface system for wind turbines with permanent-magnet synchronous generator (PMSG) and employed an integration of a generator-side three-switch buck-type rectifier and a grid-side Z-source inverter as a bridge between the generator and the grid using unity-power-factor control method and rotor-flux-orientation control method. The performances and practicalities of the designed architecture had been verified by simulations and experiments [320]. Fernandez et al. (2007) analyzed the frequency dynamic behavior in a power system with a high wind power penetration through an Eigen value analysis approach to improve the frequency dynamics behavior in a power system and also compared the wind farms equipped with squirrel cage and doubly fed induction generators [321]. Hua et al. (2011) proposed an active-damping strategy for the suppression of speed and tensional oscillations in permanent-magnet synchronous generator (PMSG)-based WTGS. Based on small-signal analysis, a low-bandwidth design for the power or generator torque controller of PMSG can help to reduce the oscillation amplitude, but the system dynamic performance is thus sacrificed [322] Anaya Lara et al. (2005) investigated the influence of DFIG based wind-farms on network operation for establishing the minimum level of synchronous generation required for the effective operation of converter-connected generation. A generic network model generation was employed for simulation [323]. Eriksson et al. (2008) studied simulations and experiments on a 12 kW direct driven PM synchronous generator for wind power and experimental results were compared to simulations regarding voltage shape and its harmonic content at rated speed. A direct driven generator is spared from losses, maintenance and costs associated with a gearbox [324].

Solum and Leijon (2007) investigated the overload capacity of a direct-driven synchronous permanent magnet wind turbine generator designed using high-voltage cable technology. The overload capability was determined by the maximum temperatures reached in the generator and in this type of machine the cables are the main heat source [325]. Alghuwainem (1999) examined the steady-state analysis and performance characteristics of stand-alone self-excited induction generator (SEIG) when a transformer is connected to its terminals to supply the load at a different voltage level or to step-up the terminal voltage for transmission. Due to speed fluctuations of unregulated wind-turbines, the terminal voltage may increase to dangerously high levels which have been reported to cause capacitor failure at wind farms. A technique for formulating and solving the system's equations including transformer saturation was also presented. The transformer tends to saturate at higher speeds, and thus absorbs the excess reactive power and limits the increase in terminal voltage and improves voltage regulation [326]. Sandra Eriksson and Hans Bernhoff (2011) evaluated the electromagnetic loss and design optimization for direct driven permanent magnet synchronous generators for wind power using an electromagnetic model. It was shown that a generator optimized for a minimum of losses will have a high overload capability [327]. Min Min Kyawand and

Ramachandaramurthy (2011) proposed a method to ensure that the double fed induction generator (DFIG) wind turbine continues to operate during severe grid faults and maintains a constant output voltage, irrespective of the fluctuating wind and also proposed controller for the DFIG wind turbine to track optimum power from the wind [328]. Zhan and Barker (2006) investigated the enhancement of the fault ride through capability of a doubly-fed induction generator, which was achieved by inserting a series-connected voltage-source converter during the fault [329].

Wenzhong Gao et al. (2009) used a real time digital simulator (RTDS) to introduce a new control strategy for LVRT for DFIG and also used current limiters which are controlled by thyristor switches to counter the effect of fault on DFIG operation [330]. Abdin and Xu (2000) performed dynamic performance analysis of a wind turbine induction generator system. The disturbances due to faults on the asynchronous as well as the synchronous part of the system possessed control problems [331]. Kasem et al. (2008) described an improved fault ride-through strategy for doubly fed induction generator-based wind turbines using decoupled controller to keep generator operating during transient grid faults [332]. Gautam et al. (2011) designed a supplementary control for the doubly fed induction generators (DFIG) power converters and also proposed the idea of adjusting pitch compensation and maximum active power order to the converter in order to improve inertial response during the transient with response to drop in grid frequency. The damping power system oscillation was observed [333]. Karrari et al. (2005) planned comprehensive control strategy for a variable speed cage machine wind generation system. The power electronic devices are generally installed between the WT and the grid where frequency is constant [334].

Bensadeq and Lefley. (2010) presented indirect vector control (IVC) for the grid operation of a Brushless Doubly Fed Twin Induction Generator to control the power flow into the grid with a variable speed prime mover such as a wind turbine [335]. Suresh Babu et al. (1995) presented a novel scheme to improve the performance of the grid connected wind-driven induction generators by using a microcontroller for reducing applied voltage during partial load conditions and at starting [336]. These reviews will be useful for effective operation of generators to produce wind energy.

14. Conclusion

The advanced research capabilities on wind energy are expected to stimulate economic development and enhance environmental quality. The recent research and development carried out on wind energy has been reviewed as follows.

- The wind resource assessment techniques and models are used to estimate the wind power potential and the wind power density, site selection and site matching, estimating and forecasting of the wind energy production and the energy loss due to wake effect.
- The numerical optimization technique and methods are used to reduce wind turbines noise. The standard IEC 61400-11 is used to assess noise emission on the wind turbine generator systems
- Effective grid integration methods are used to avoid losses in energy transfer. The modulation techniques are used to identify the problems associated with the existing grid connection. The latest technical issues related to grid integration are identified to reduce the loss of power.
- The pitch control, active control, adaptive fuzzy logic control, the fuzzy neural network control and the artificial neural network technique are used to control and to improve the quality of the power generated from wind turbine system. The testing of the control system of WTGs is carried out as per international standards. The reviews on control strategies of wind turbine will be useful to reduce vibration, noise and power regulation of WTGS to capture maximum wind energy from wind farms.
- The dynamics model is used to study the real behavior of offshore wind turbines in the marine environment. The offshore wind energy production faces a wide range of new challenges in design, development, manufacturing, installation, maintenance and operation.
- The hybrid energy techniques are used to meet the load requirements for remote village electrification and also to predict the performance and the cost of hybrid energy systems. The technical and economical feasibility studies are useful to promote hydrogen production from wind energy and other renewable energy sources.
- The hydrogen production from renewable energy is used to meet the world's energy requirements. The review indicated that the technical and economical feasibility of wind - hydrogen integrated systems will draw more attention in the near future.
- The main prominent instrument for the development of wind energy is a feed-in tariff. The review reveals that the feed in tariff is more effective in many countries. There is no FIT mechanism has been proposed for wind energy in Malaysia. The FIT policies can help to reduce both economic and noneconomic barriers in renewable energy development.
- The model analysis of wind turbine components is used to secure the smooth and reliable operation of wind turbine generators. It also used to reduce the risks and to improve the design of wind turbine components.
- The reviews on performance of wind turbine generators and wind farms are used to predict, compare and improve power generation from wind energy.
- The economic analysis of wind energy is used to evaluate the cost of wind energy generation, annual electrical energy production, installation cost, cost of the land, transmission cost, cost of operating and manufacturing & maintenance costs. The optimal kind and size of WTGs can be determined for each installation area. The probabilistic models are used to calculate the long-term market clearing prices and wind farm revenues.
- The generator is used to convert mechanical energy into electrical energy. The simulation models are used to evaluate the performance of synchronous and double fed induction generators. The model analysis, fault ride capability, grid interface with generators, active damping and comprehensive control strategies, over load capacity investigation, performance characteristics and minimization of electromagnetic losses of generators will be useful for enhancement of wind energy production.

The presented methods and discussions in this review paper will be useful to wind energy planners, policy makers, decision makers and wind turbine components manufactures for further improvements. It is concluded that only a less number of authors have worked on the reliability evaluation of wind-hybrid systems. Further research in wind energy systems and hybrid wind energy systems will be fruitful to meet the power requirements of any country.

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